

Hyperspectral Imaging Polarimeter

Jeff W. Rish, III
Coastal Systems Station
7603 W. Highway 98
Panama City Beach, FL 32407
Phone: (850) 234-4834 Fax: (850) 235-5462 E-mail: rishjw@ncsc.navy.mil

Joe Foster
Nichols Research Corporation, a unit of Computer Sciences Corporation
1130 North Eglin Parkway
Shalimar, FL 32579
Phone: (850) 796-3912 Fax (850) 651-1108
E-mail: jfoste26@csc.com, fostersail1@yahoo.com

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LONG-TERM GOAL

The long-term goal of the program is to develop and demonstrate a prototype, tunable, polarimetric imaging system supporting special reconnaissance operations.

OBJECTIVES

The current objectives of the Hyperspectral Imaging Polarimeter (HSIPOL) program are to: 1) confirm findings and refine recommendations from sensor concept assessment study through data collection activities; 2) develop, characterize and demonstrate a field-portable, intensified, Stokes vector, polarimetric imaging system; and 3) demonstrate operator oriented polarization products.

APPROACH

A two-phase approach has been employed to accomplish the stated objectives of this project. In the initial phase, CSC-Nichols and CSS employed a process designed to identify and to evaluate the tactical benefits of a spectral polarimeter and to recommend a path for the development of future hardware. The task began with an application study to generate mission requirements that were used to focus the analysis and data collection work. The approach included the collection of spectropolarimetric signature data for selected materials. These data were then used in a series of target signature studies that were designed to evaluate the potential performance of various types of imaging systems, taking a wide variety of environmental conditions into account. The signature studies identified the visible and long-wavelength infrared spectral bands as the spectral regimes that would provide the highest payoff for systems developed for Naval Special Warfare (NSW). Nichols then performed an assessment of sensor concepts for a tunable polarimetric imaging system for NSW that culminated in a preliminary design study. A beam splitting pyramid concept that would enable the development of a full Stokes vector polarimeter built on an intensified visible imaging platform was identified as the option providing the least technical, cost, and schedule risk, and was proposed for future development. A data collection activity using existing sensors was subsequently planned and

executed to further refine the understanding of the phenomenology and to provide evidence of Special Operations Forces (SOF) military utility for the recommended hardware development option.

The second phase of the effort involves the development, characterization, and demonstration of a full Stokes vector imaging polarimeter based on the beam splitting pyramid polarimeter concept recommended for development under the first phase of the study. The concept relies on the demonstrated premise that a pyramid beam splitter can be used to subdivide a scene into four equivalent images. These images are then simultaneously passed through a set of collaterally aligned polarization filters onto an imaging array. The filters are arranged in a quadrant configuration consisting of a set of polarization components from which the Stokes vector can be derived. One possible arrangement consists of intensity, 0° linear polarization, 45° linear polarization, and right circular polarization. The measured intensity fields beyond the four filters are co-registered and can then be used in combination to generate the Stokes vector for the incident light field. An illustration of the concept is shown in Figure 1.

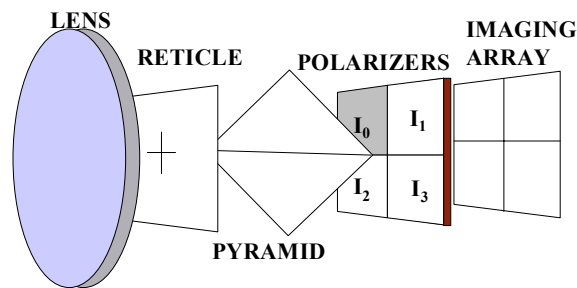


Figure 1. Beam-splitting pyramid visible polarimeter concept.

The polarimeter development process will include a set of critical laboratory experiments to verify that performance goals are being achieved, and a thorough characterization of both the individual components and system as a whole will be performed to ensure the validity of the measurements that will subsequently be performed in the field. Upon verification that the polarimeter is functioning properly, field tests will be performed with the instrument over diurnal cycles, at different times of the year, and in different environments. This data will provide an understanding of the variability of visible polarimetric signatures. Laboratory signature data for various materials will be used to evaluate the data collected in the field. The data will be analyzed to identify trends that will lead to the development of effective polarization exploitation techniques.

WORK COMPLETED

The last remaining aspect of the initial assessment phase of the HSI POL program was a data collection activity designed to gather information in support of the hardware development recommendations. It was originally intended that the team would use polarimetric sensors that were being used in a MASINT program sponsored by another agency. However, access to these sensors proved to be a problem, and an alternative approach had to be pursued to collect the required field data.

In January 2000, a set of simple experiments was performed in the non-magnetic area at CSS to demonstrate the utility of a passive polarimeter for nighttime operations. A Nighthawk Silicon Intensifier Target (SIT) camera (Figure 2a) with a linear polarizer attached to the front of the camera system was adapted for use as a baseline system. The linear polarizer was mounted such that it could

be manually rotated as shown in Figure 2b. It was also indexed for the polarizer angles of 0, 45, 90, and -45 degree orientation of the pass axis referenced to horizontal. The Nighthawk SIT is essentially an image intensified CRT video camera system capable of producing 525 horizontal lines of resolution with 11 shades of gray at 30 frames per second. The light level sensitivity of the camera is specified at .001 foot-candles (0.01 lux).

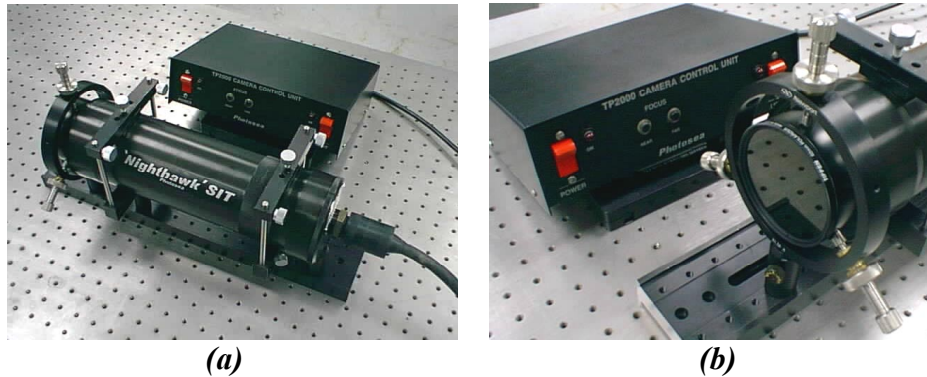


Figure 2. Nighthawk SIT camera with linear polarizer attached.

The experiments consisted of qualitative measurements performed on various target materials under moonlight conditions at various look-angles and distances from the instrument. Data collected during the experiments were analyzed for trends following the tests.

CSC-Nichols Research completed and delivered a draft report documenting the initial feasibility assessment, the design study, and the data collection activities performed to date.¹

Contract negotiations for the CSC-Nichols hardware development proposal have been completed and a multi-year contract has been awarded to develop the beam-splitting intensified visible polarimeter. CSS and CSC-Nichols will work collaboratively on testing the instrument and analyzing the data.

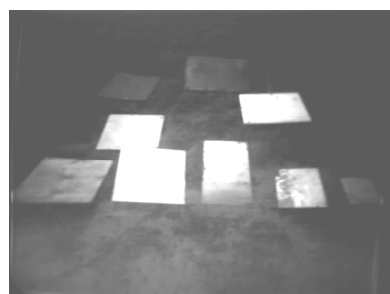
RESULTS

Analysis of the data from the passive visible nighttime polarimetric imaging experiments indicate substantial potential for the approach to be used to successfully discriminate between man-made and natural objects in the visible wavelengths at night.

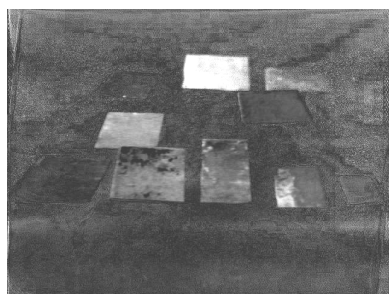
The experiments were conducted in the non-magnetic area of CSS. Primary targets were a resolution panel, and an array of flat targets consisting of various target materials ranging from rubber (mud flap) to shingles for dielectrics, and from painted aluminum to stainless steel for conductors. The shingles material sample was constructed of common, gray roofing shingles with plywood backing. Included in the target set was a 1/4"-thick steel plate with rust on the surface; a piece of 1/2" blue-tinted, exterior housing insulating material; and, a 1/4"-thick aluminum plate that had two coats of OD green Krylon paint on the surface. The stainless steel sample was 1/8" thick.

The experiment was designed to only provide qualitative data since the camera gain is controlled internally according to ambient light conditions. Due to the inability to control the gain on the intensifier and the iris, the camera cannot be calibrated and thus used to provide good quantitative

measurements until modifications are made to the AGC circuitry. The results do however show the promise of using an intensified polarimeter at night. The first set of results is for the materials target field and the intensity and DOLP images are shown in Figure 3. Statistics were extracted from each of the material samples and are presented in Table 1. Notice that the black rubber has a significant amount of polarization ($>20\%$). The sheetrock also has a strong polarization signature. The aluminum plate, glass plate, and Plexiglas have measurable signatures that distinguish them from the background. The rusted steel, shingles, Styrofoam, and plywood all have very small polarization signatures. These results are consistent with anticipated results. The rubber, glass, aluminum, and sheetrock all have smooth, specularly reflective surfaces, which lead to large polarization signatures. The rusted steel, shingles, Styrofoam, and plywood all have very rough almost diffuse surfaces, which lead to almost no polarization. The background has a small polarization signature. Table 1 also contains a measure of the signal to clutter ratio (SCR) for each of the materials against the background. It becomes obvious that the above-mentioned specular materials have a SCR greater than one and in several cases (rubber, and sheetrock) greater than five. The DOLP histograms shown in Figure 4 further illustrate the separability of several of the materials.



Intensity



DOLP

Figure 3. Intensity and degree of linear polarization for targets.

Although the test was not designed to produce quantitative results, it definitely demonstrated the presence of strong visible polarimetric signatures at night. This was predicted in the signature modeling, but to our knowledge, no one has previously demonstrated visible polarization imagery under these conditions. The test should be

Table 1. Comparison of DOLP for targets.

Material	Mean	Standard Deviation	SCR
Aluminum	0.100	0.044	1.399
Stainless Steel	0.062	0.018	0.427
Rusted Steel	0.104	0.039	1.563
Rubber	0.266	0.032	6.777
Sheetrock	0.148	0.013	5.594
Glass	0.077	0.024	0.942
Plexiglas	0.084	0.034	1.009
Plywood	0.023	0.012	1.793
Insulator Board	0.042	0.009	0.836
Shingles	0.034	0.017	0.845
Background	0.052	0.028	0

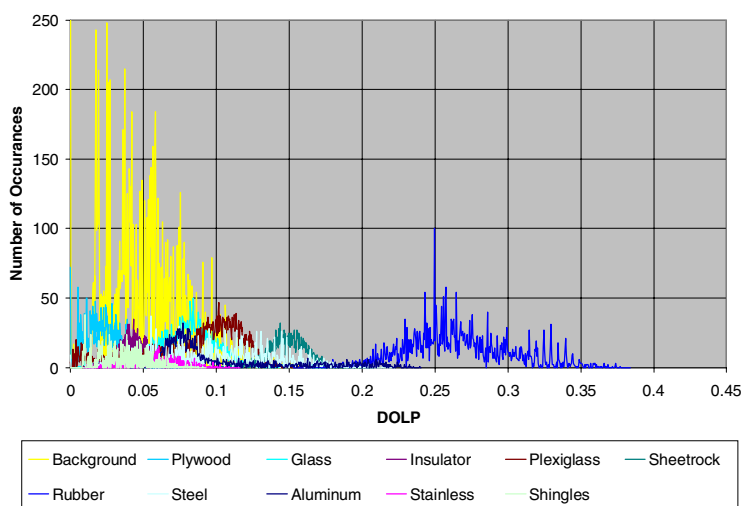


Figure 4. DOLP Histograms.

followed up with a more rigid testing approach, which produces some precise polarization measurements. A sensor which has hard wired control over the intensifier gain and aperture iris is required, as any changes in the sensors response of the data collection interval will be interpreted as a polarization signal. Furthermore, tighter control over the orientation of the linear polarizer is required to ensure repeatable results. Finally, the system must be calibrated in a laboratory before being taken out to the field for data collection activities.

IMPACT/APPLICATIONS

There is a critical need for advanced reconnaissance, surveillance, targeting, and acquisition sensors for Special Operations Forces. There are several areas where a light-weight, man-portable imaging system would be required, for example, special reconnaissance, night vision (NV) systems, and thermal weapons sights. The potential mission areas that require advanced electro-optical imaging capabilities are: detection and identification of low-contrast, disguised, or camouflaged man-made targets; viewing objects through obscurants or behind light-weight obstructions; stand-off characterization of terrain features that may impact mission execution; early detection of chemical spills, dumping areas, hazards, or release of chemical warfare agents; detection of mines, munitions, and trip wires; and assessing the existence of prior activity in an area on the basis of disturbed or stressed terrestrial features such as earth and vegetation. Polarimetry has been demonstrated to contribute to the successful performance of the aforementioned missions.

TRANSITIONS

This project is currently jointly funded by both the ONR NSW technology base program and the U.S. Special Operations Command (USSOCOM). A logical transition after the prototype demonstration phase would be through a USSOCOM technology development program.

RELATED PROJECTS

Two projects of direct relationship to the current effort are the Shallow Water Imaging Polarimeter project (SHRIMP), and the Tunable Filter Multispectral Camera (TFMC) program. SHRIMP is an ONR-sponsored passive underwater imaging system that simultaneously collects and co-registers optical image information for three different linear scene polarization states. Preliminary in-water tests of the SHRIMP are slated to take place in the Fall of year 2000. The TFMC system is a 4-channel airborne sensor that has been developed by the Marine Corps as a minefield detection system.

CSC-Nichols has received funding from the Department of Defense, commercial sources, and congressionally directed plus-up money to rapidly advance the state-of-the-art of infrared polarimetric sensors for use in surveillance applications. Under this program, Nichols is developing real-time polarization sensors and data processing systems.